

# KOPIO TN075

## Photon veto inefficiency due to dead material in the barrel veto

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### Abstract

The effect on the photon veto inefficiency of dead material in the KOPIO barrel veto for  $K_L^0 \rightarrow \pi^0\pi^0$  events was studied with the KOPIO GEANT Monte Carlo v06\_2. There is essentially no change in the photon veto inefficiency for up to 2 mm of dead material (iron) between barrel veto modules for a 1 MeV threshold.

## 1 Introduction

The cross-section of a “log-style” barrel veto (BV) module as implemented in the KOPIO GEANT Monte Carlo v06\_2 is shown in Figure 1. The BV is composed of eight such modules in depth with a total thickness of 17.2 radiation lengths for normal incidence. The lead-scintillator stack is wrapped with steel (modelled as iron). For a thickness of 0.01 cm, the wrapping contributes 0.1 radiation lengths at normal incidence. The effect of varying the thickness of this steel wrapping was studied. The total width of a module is fixed at 15.01 cm, so increasing the thickness of the wrapping results in a corresponding decrease in the width of the scintillator and lead. Note that a wrapping thickness  $t$  contributes a transverse thickness of  $2t$  of dead material between the active area of the modules.

$K_L^0 \rightarrow \pi^0\pi^0$  decays were generated with wrapping thicknesses of 0.01, 0.05, 0.10, 0.20 and 1.00 cm. The  $K_L^0 \rightarrow \pi^0\pi^0$  were required to decay in a fiducial decay region ( $1040 < Z < 1390$  cm or 25 cm from the ends of the decay region) and at least two of the photons from  $\pi^0$  decays must satisfy  $|X| < 201.6$  cm and  $|Y| < 201.6$  cm when projected to the front of the PR and these two photons must have an invariant mass within 50 MeV of the  $\pi^0$  mass. In addition, at least one of the photons from  $\pi^0$  decays must not project to  $|X| < 201.6$  cm and  $|Y| < 201.6$  cm at the front of the PR. The threshold for transport of all particles was set to 100 keV for these studies. This study used GEANT3 which does not simulate photonuclear effects. The observed energy  $E_{\text{obs}}$  is the sum of the energy deposited in the scintillator layers, neglecting photo-statistics, after propagation to each end of each scintillator assuming a 200 cm attenuation length. So an energy deposit  $E_{\text{dep}}$  in the middle of a 4 m long counter will give  $E_{\text{obs}} = E_{\text{dep}} \times e^{-1}$ . The relative timing of  $E_{\text{obs}}$  is ignored in this study.

## 2 Results

The inefficiency as a function of the photon energy  $E_\gamma$  for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV (here  $E_{\text{obs}}$  is the total observed energy of the photon) is shown in Figures 2, 3, 4, 5 and 6 for wrapping thicknesses of 0.01, 0.05, 0.10, 0.20 and 1.00 cm, respectively. The increase in photon veto inefficiency that begins at  $E_\gamma \approx 150$  MeV is due to insufficient coverage in the downstream region, primarily due to photon trajectories that just miss or partially traverse the beam catcher [1] and also due to photon trajectories that traverse regions where neighboring detectors do not have enough overlap. More work is needed to optimally place detector elements to ameliorate this situation.

Only photons that do not project to  $|X| < 201.6$  cm and  $|Y| < 201.6$  cm at the front of the PR are considered for the studies of the wrapper thickness on the photon veto inefficiency. Figures 7, 8, 9, 10 and 11 compare the photon veto inefficiency for wrapping thicknesses of 0.01, 0.05, 0.10, 0.20 and 1.00 cm as a function of  $E_\gamma$  for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV, respectively.

I attempted to fit photon veto inefficiency  $\bar{\epsilon}$  as a function of wrapper thickness with two functional forms  $\bar{\epsilon} = \bar{\epsilon}_0 \times (1 + R_1 t)$  and  $\bar{\epsilon} = \bar{\epsilon}_0 \times (1 + R_2 t^2)$  where  $R_1$  or  $R_2$  is the relative increase in photon veto inefficiency per cm or  $\text{cm}^2$  of wrapper and  $\bar{\epsilon}_0$  is the inefficiency for zero wrapper thickness. The latter function approximates the probability  $\mathcal{P}$  that a photon goes undetected due to the wrapper  $\mathcal{P} \propto (2t/w) \times (1 - \exp(-t/R_M)) \propto t^2/wR_M + \mathcal{O}(t^3/wR_M^2)$  where  $t$  = wrapper thickness,  $w$  = module width and  $R_M$  = Moli  re radius of iron ( $\approx 1.7$  cm [2]). Neither functional form provided reliable fits over the full range of thicknesses and thresholds.

In lieu of such fits, I produced some plots of the photon veto inefficiency as a function of wrapper thickness and energy threshold for representative photon energies from 5 to 95 MeV in Figure 12.

## 3 Conclusions

For an observed energy threshold of 1 MeV and photon energies above 20 MeV, there is essentially no difference in the photon veto inefficiency for wrapper thicknesses from 0.01 to 0.1 cm. Below 20 MeV, the inefficiency increases by less than a factor of 2 for this wrapper thickness range. For higher thresholds, even a 0.05 cm wrapper thickness causes some increase in inefficiency with respect to a 0.01 cm thickness. Note that photonuclear interactions, which are not simulated by GEANT3, may be important in the low energy regime and could modify these conclusions.

## 4 Acknowledgements

Thanks to Laur Littenberg and Michael Sivertz for useful comments on an early draft of this note.

## References

- [1] This lack of coverage near the beam catcher was also noted by H. Morii in the KOPIO DS Charged Veto Meeting, 7 November 2003,

Pb = 0.1, Scint = 0.7, wrapper = 0.1 cm

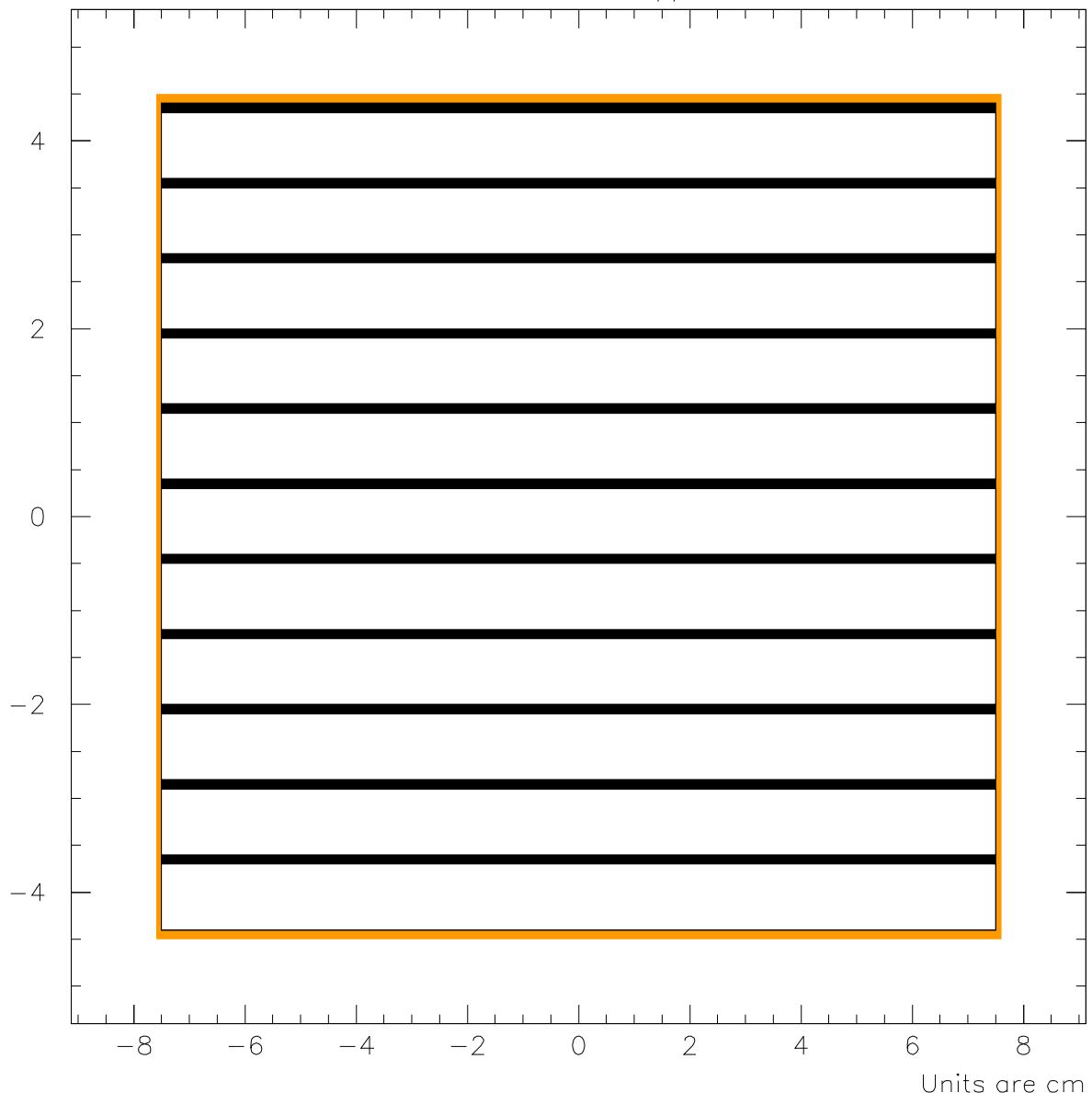


Figure 1: Cross-section of a barrel veto module in GEANT. The module consists of 11 7mm scintillator (white) and 1mm Pb layers (black) with a steel wrapping (yellow). For this example the wrapping is 1mm thick.

[http://pubweb.bnl.gov/users/e926/www/meetings/DCV/nov07\\_03/catcher\\_design.pdf](http://pubweb.bnl.gov/users/e926/www/meetings/DCV/nov07_03/catcher_design.pdf).

[2] Section 26 of the Review of Particle Properties 2002

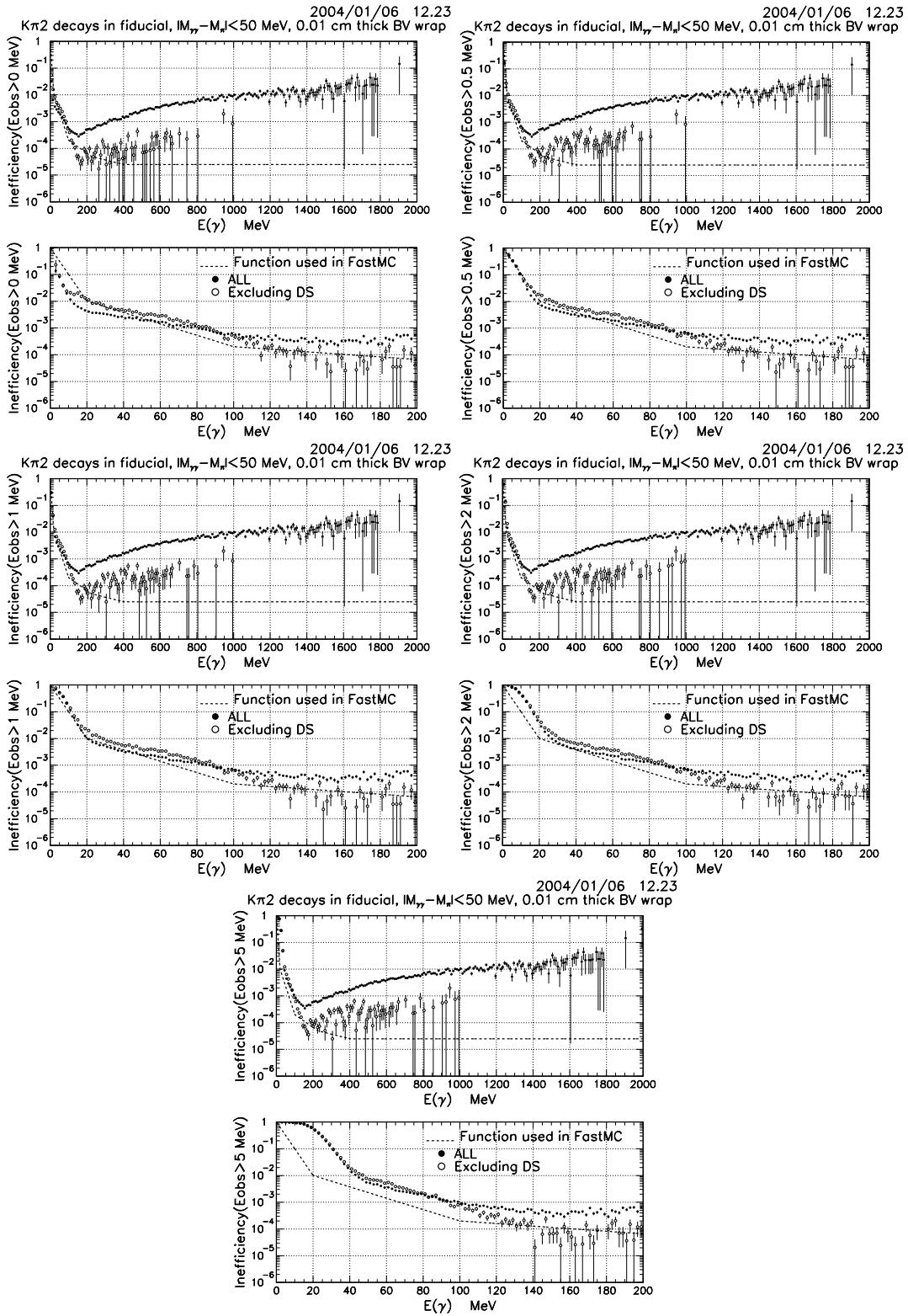


Figure 2: Photon veto inefficiency for **0.01 cm wrapper thickness** for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV starting from upper left. Upper(lower) plots show  $E_{\gamma}=0,2000(200)$  MeV. Filled points show total inefficiency, open points show the inefficiency excluding photons with trajectories that strike the preradiator or go into the beam pipe hole. For comparison the functional form of the photon veto inefficiency used in the FastMC for the TDR is shown as a dashed line.

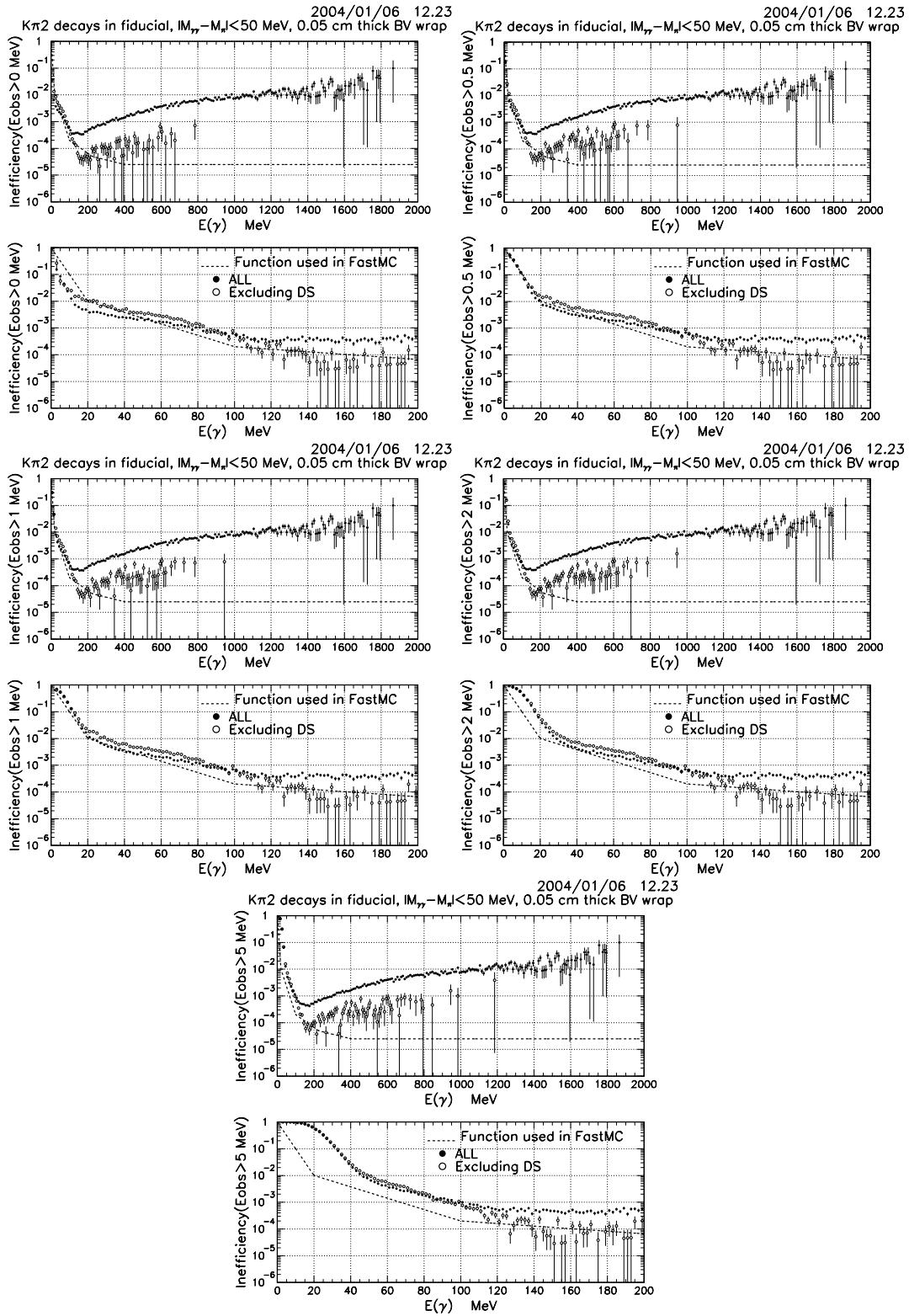


Figure 3: Photon veto inefficiency for **0.05 cm wrapper thickness** for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV starting from upper left. Upper(lower) plots show  $E_{\gamma}=0,2000(200)$  MeV. Filled points show total inefficiency, open points show the inefficiency excluding photons with trajectories that strike the preradiator or go into the beam pipe hole. For comparison the functional form of the photon veto inefficiency used in the FastMC for the TDR is shown as a dashed line.

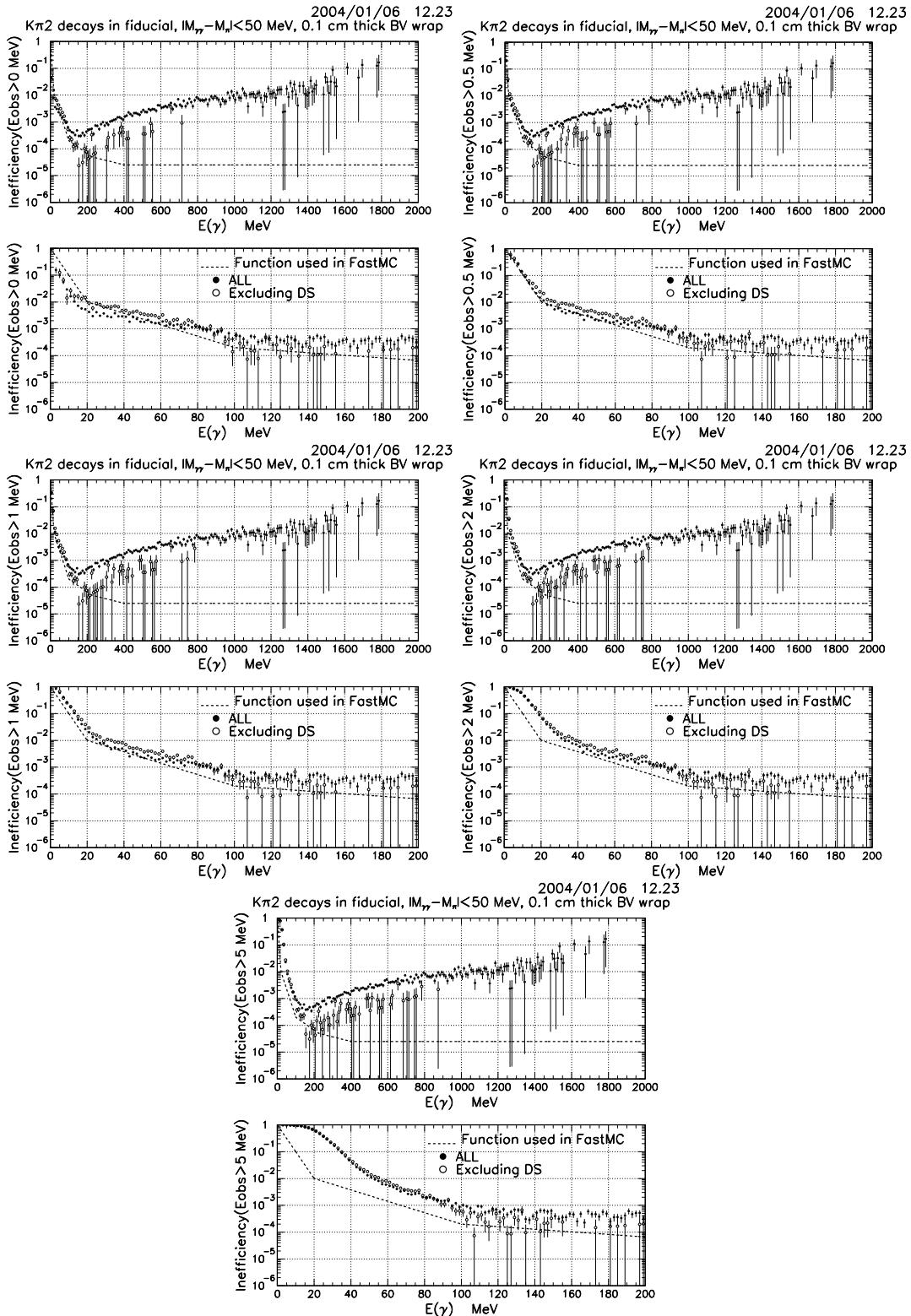


Figure 4: Photon veto inefficiency for **0.10 cm wrapper thickness** for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV starting from upper left. Upper(lower) plots show  $E_\gamma=0, 2000(200)$  MeV. Filled points show total inefficiency, open points show the inefficiency excluding photons with trajectories that strike the preradiator or go into the beam pipe hole. For comparison the functional form of the photon veto inefficiency used in the FastMC for the TDR is shown as a dashed line.

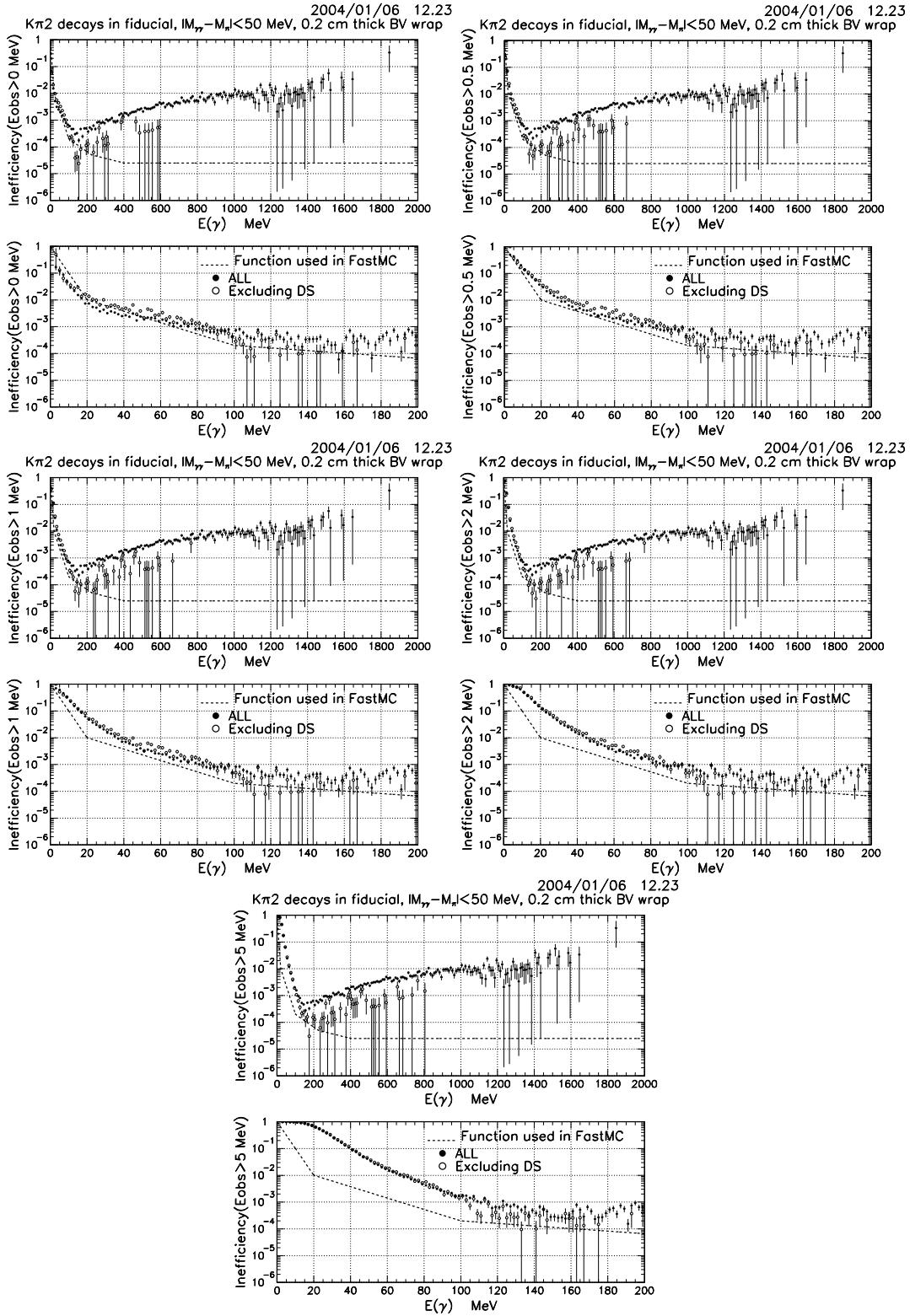


Figure 5: Photon veto inefficiency for **0.20 cm wrapper thickness** for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV starting from upper left. Upper(lower) plots show  $E_{\gamma}=0,2000(200)$  MeV. Filled points show total inefficiency, open points show the inefficiency excluding photons with trajectories that strike the preradiator or go into the beam pipe hole. For comparison the functional form of the photon veto inefficiency used in the FastMC for the TDR is shown as a dashed line.

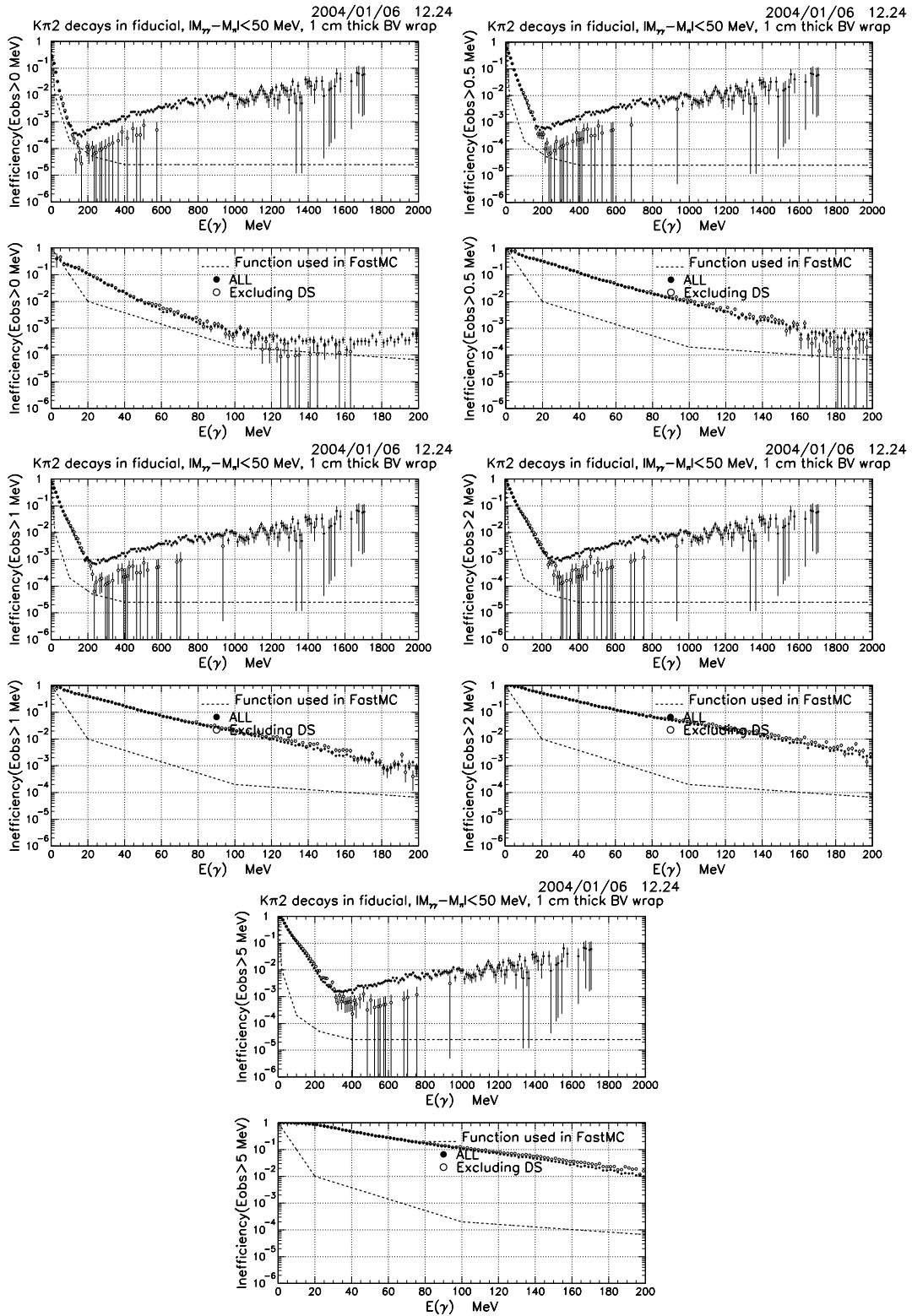


Figure 6: Photon veto inefficiency for **1.00 cm wrapper thickness** for  $E_{\text{obs}} > 0$ , 0.5, 1.0, 2.0, and 5.0 MeV starting from upper left. Upper(lower) plots show  $E_{\gamma}=0,2000(200)$  MeV. Filled points show total inefficiency, open points show the inefficiency excluding photons with trajectories that strike the preradiator or go into the beam pipe hole. For comparison the functional form of the photon veto inefficiency used in the FastMC for the TDR is shown as a dashed line.

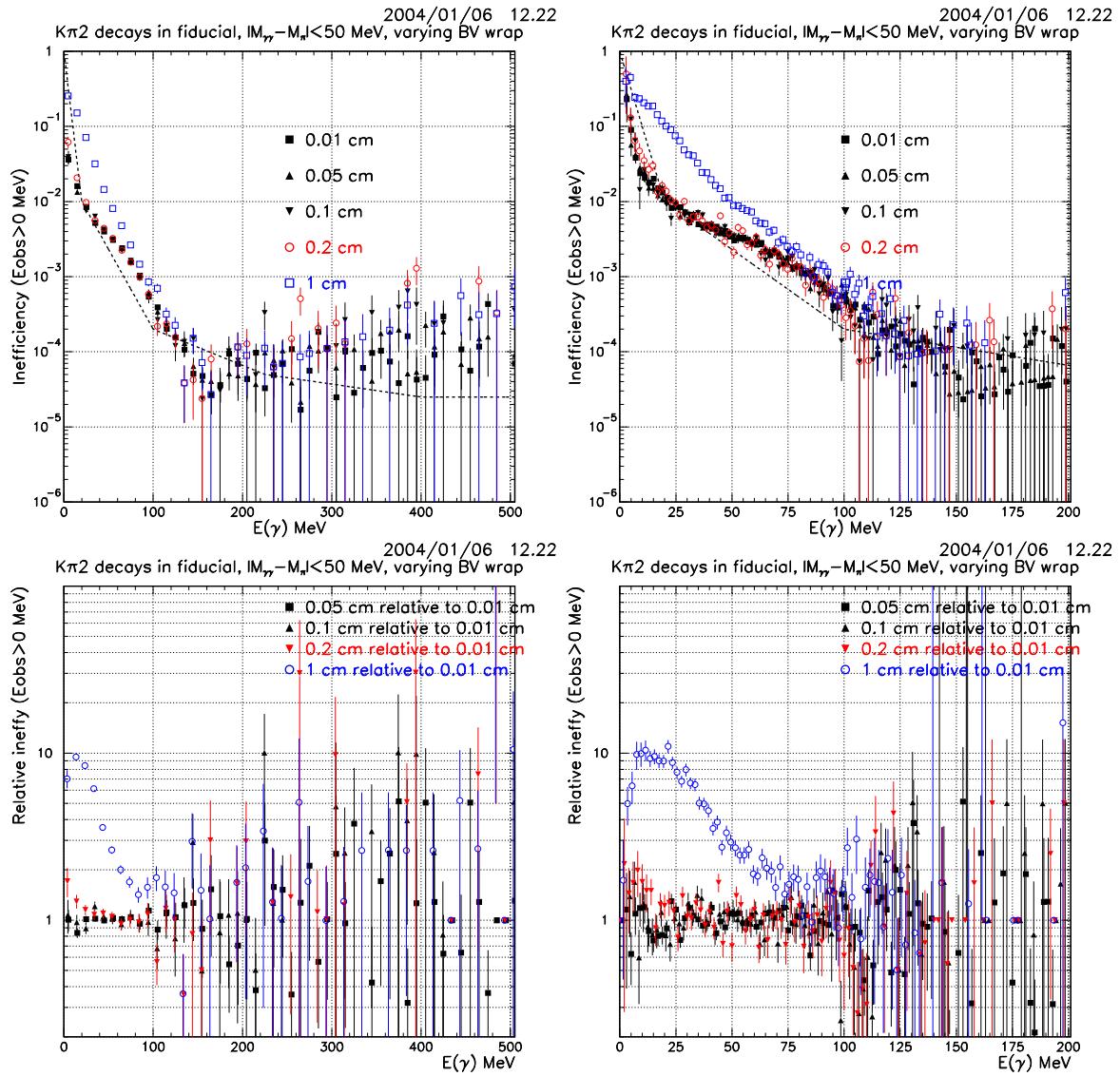


Figure 7: Upper plots show photon veto inefficiency for  $E_{\text{obs}} > 0$  MeV. Lower plots show the photon veto inefficiency relative to 0.01 cm wrapper thickness. Left(right) side is  $E_{\gamma} = 0, 500(200)$  MeV range.

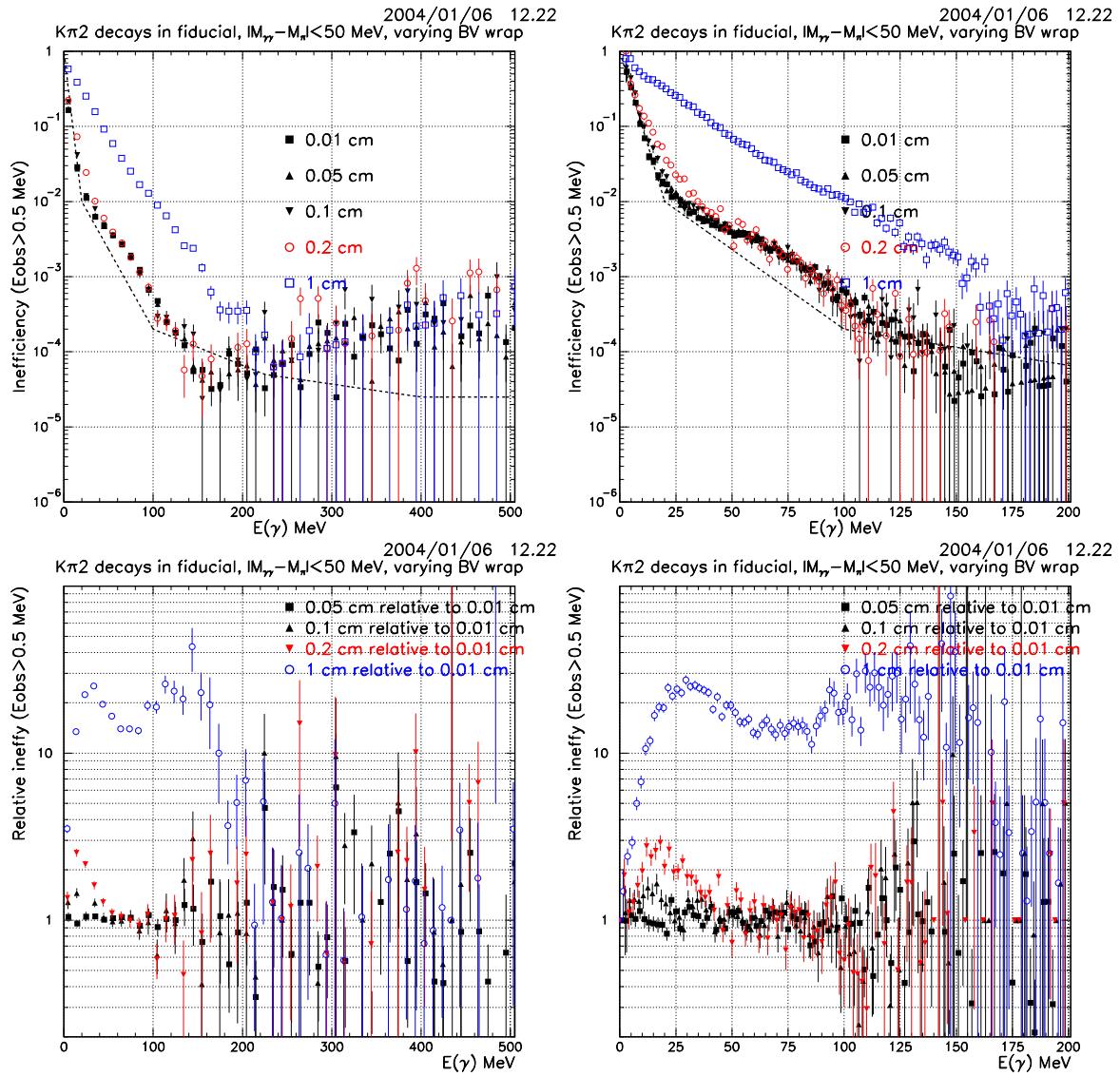


Figure 8: Upper plots show photon veto inefficiency for  $E_{\text{obs}} > 0.5$  MeV. Lower plots show the photon veto inefficiency relative to 0.01 cm wrapper thickness. Left(right) side is  $E_\gamma = 0, 500(200)$  MeV range.

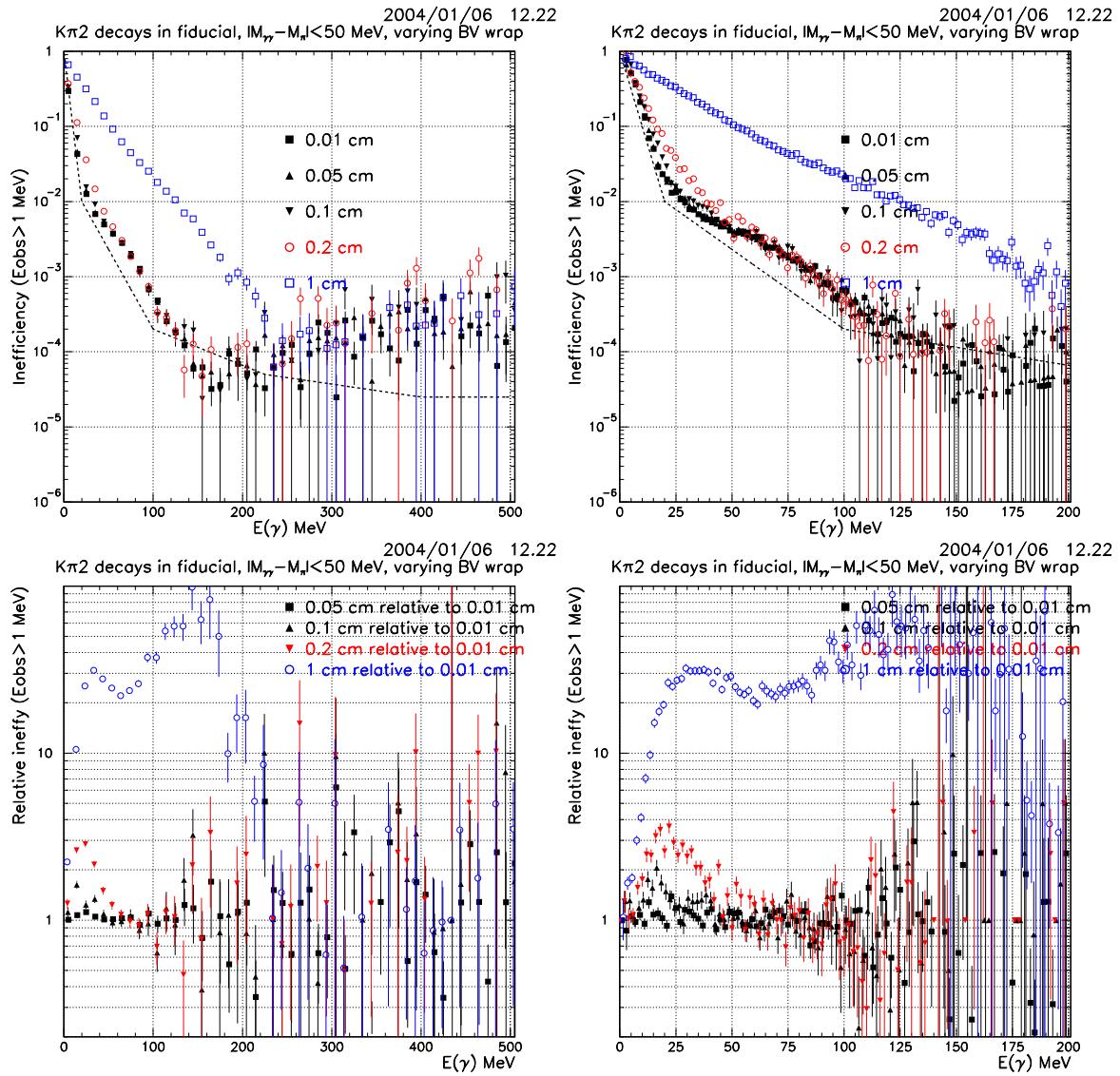


Figure 9: Upper plots show photon veto inefficiency for  $E_{\text{obs}} > 1.0$  MeV. Lower plots show the photon veto inefficiency relative to 0.01 cm wrapper thickness. Left(right) side is  $E_\gamma = 0, 500(200)$  MeV range.

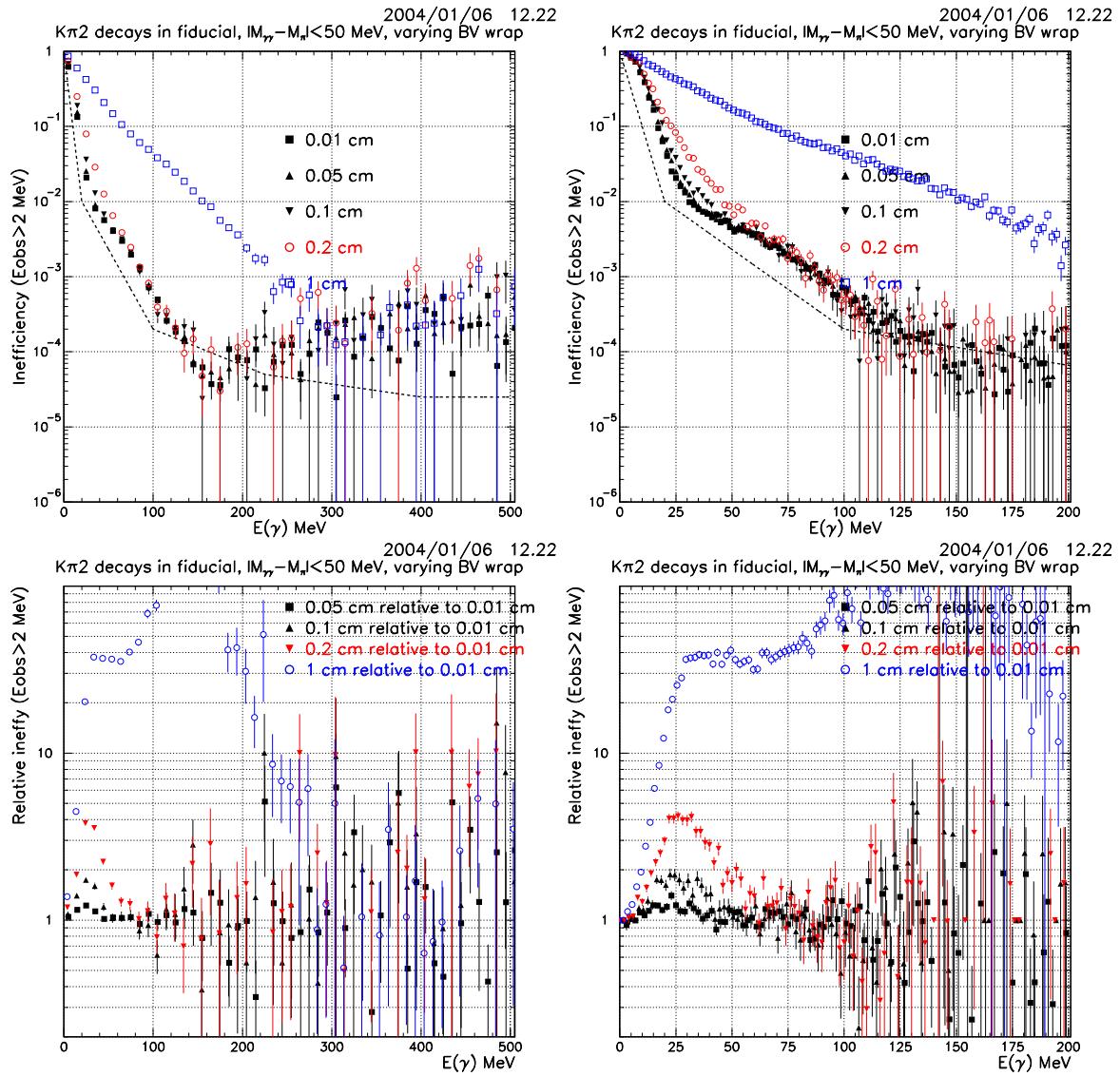


Figure 10: Upper plots show photon veto inefficiency for  $E_{\text{obs}} > 2.0$  MeV. Lower plots show the photon veto inefficiency relative to 0.01 cm wrapper thickness. Left(right) side is  $E_\gamma = 0, 500(200)$  MeV range.

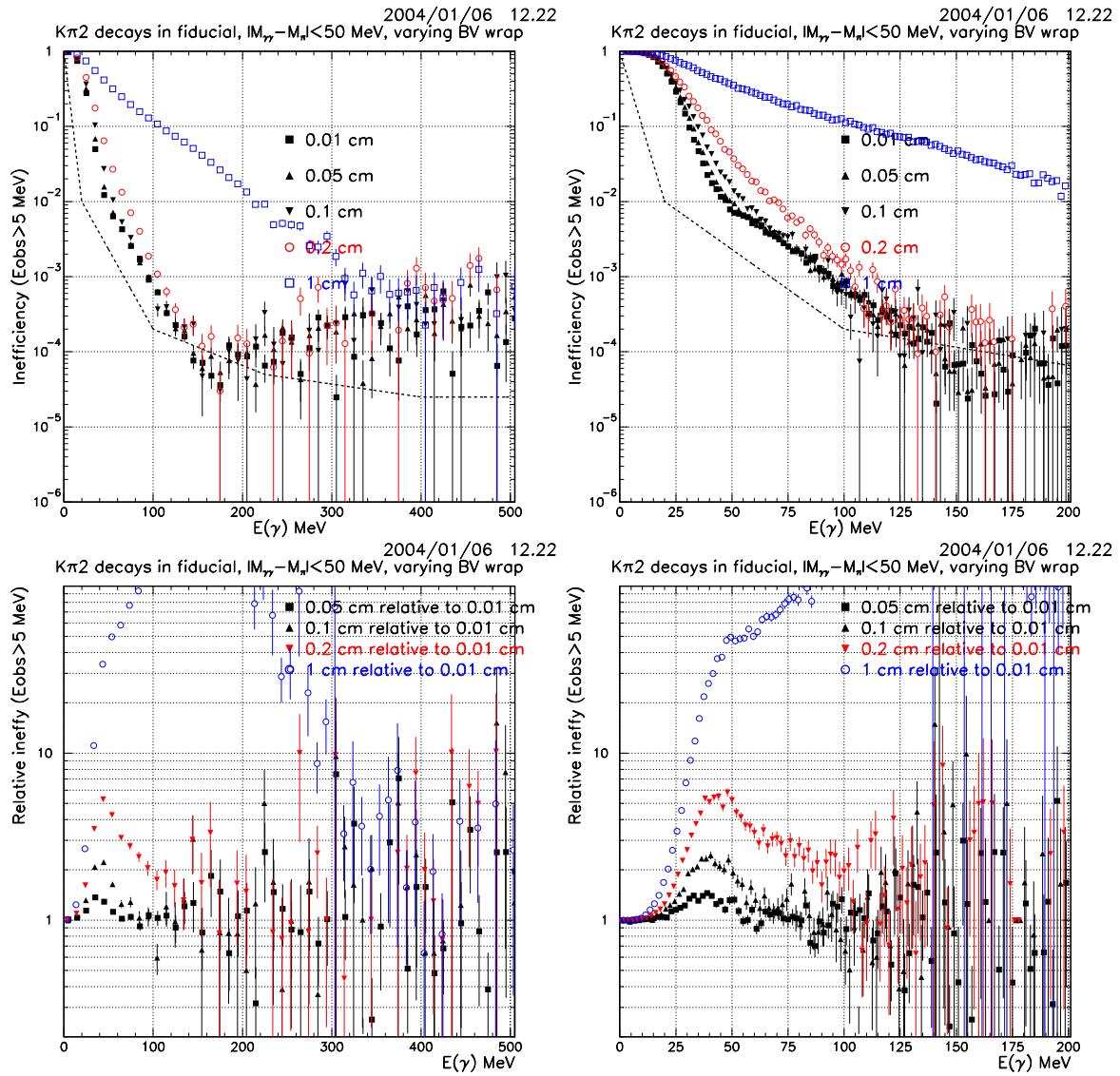


Figure 11: Upper plots show photon veto inefficiency for  $E_{\text{obs}} > 5.0 \text{ MeV}$ . Lower plots show the photon veto inefficiency relative to 0.01 cm wrapper thickness. Left(right) side is  $E_\gamma = 0, 500(200) \text{ MeV}$  range.

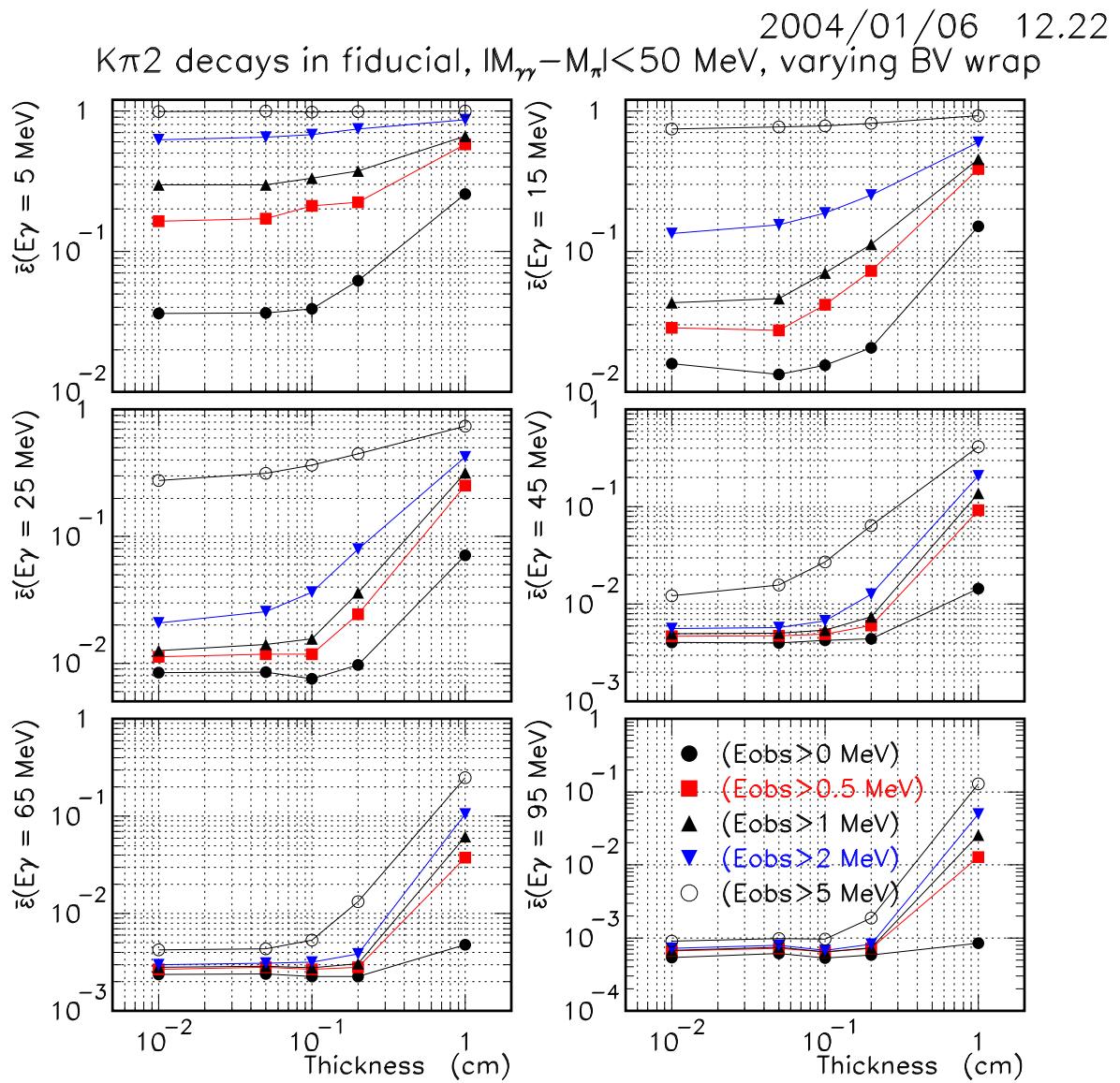


Figure 12: Photon veto inefficiency as a function of wrapper thickness and energy threshold for six photon energies. The photon energy range is  $\pm 5$  MeV about the value given, so the upper right plot is for  $10 < E_\gamma < 20$  MeV. Points with the same energy threshold are connected with a solid line to guide (or fool) the eye.